Pre-print # LBL-20533
5th November 1985

Peculiar optical and IR behaviour in type I supernovae, and the origin of the 1.2μm absorption.

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Summary

A small number of type I supernovae exhibit well defined peculiarities. In particular some type I supernovae do not have the characteristic 6150Å feature and some do not have the 1.2μm absorption. It is noted that all SN which lack the infrared absorption also lack the 6150 Å feature which is attributed to Si II. It is proposed that these supernovae constitute a single sub-class and that Si could be responsible for the strong unidentified infrared absorption which is characteristic of classical SNI. Si I has a dense array of strong lines in the near infrared so this ion could be responsible for the dominant features of SNIa IR behaviour. If this hypothesis is vindicated by subsequent observations or by calculation of synthetic spectra then it is most likely that the difference between ordinary supernovae and these peculiar ones is the abundance of Si.

1)Introduction

The first infrared (IR) observations of type I supernovae (SNI) suggested that they possesed a remarkable degree of uniformity (Elias et al. 1981), thus confirming the findings from optical observations that SNI are on the whole very homogenious. The IR light curves of the first three SNI observed at IR wavelengths are so similar that they can be overlaid upon one another with no discrepancy between the three events becoming apparent. However, IR observations of SNI 1983n (Meikle et al. 1984) upset this picture by demonstrating that the IR evolution of at least some type

I's is substantially different from the supernovae of Elias et al.(1981). From a compilation of IR photometry of 13 SNI Elias et al. (1985) have shown that it is possible to divide SNI into two subclasses. The majority of their type I supernovae, SNIa (following their nomeclature), show strong, unidentified absorption at 1.2μm which leads to very red J-H colours, and is thought to be responsible for producing a secondary maximum in the IR magnitudes. The J-H colours of Type Ib (of which Elias et al. 1985 cite three examples) are significantly bluer than the J-H colours of type Ia indicating that the 1.2μm absorption is absent. SNIb also show no secondary maximum and have a slower decline.

Interpretation of the red J-H colours of SNIa as due to a strong absorption at 1.2μm is best illustrated by the broad-band energy distribution derived by Branch et al. (1983) from photometry which spans from 0.25μm to 2.2μm. These spectra show that at J the energy distribution is depressed below a black-body curve which fits both optical and longer wavelength observations. The absorption sets in after maximum light and persists for at least the first 100 days. To date no explanation has been proposed for the IR absorption. This is remarkable given the success of the interpretation of optical spectra in terms of resonant scattering by neutral and singly ionized metals above a photosphere. The major handicap is of course the lack of IR spectra of SNI. Without a precise wavelength measurement of the feature it would be hazardous to suggest the cause. However, I propose that there is evidence from the optical spectra of SNIb that suggests a likely culprit. In §2 optical and IR observations of all four known SNIb (SN1982r, SN1983i, SN1983n and SN1984l) are discussed. It is noted that the optical spectra of all of these SNIb are peculiar because they lack the 6150Å absorption. It is therefore concluded that the optical and IR peculiarity are characteristics a single sub-type of SNI. In §3 the role of Si in the spectrum is evaluated, and it is pointed out that Si I has strong IR lines at 1.2μm, and thus a low abundance of Si in type Ib could explain the unusual optical and IR spectra of these SN.

2)Peculiar behaviour in the optical and infrared

SN1983n is the archetypal SNIb, being the first SNI which was recognised as being radically different from those observed by Elias et al. (1981) (Meikle et al. 1984). SN1983i and SN1984l are similarly characterised as a SNIb on the basis of their slow decline and unusually blue J-H colours (Elias et al. 1985). Infrared photometry of SN1982r by Koornneef (Muller, 1982b) and by Graham (1985) show that the J-H colours of this SNI were bluer than SNIa by about one magnitude on days 20 and 57 after maximum, and thus, being similar to SN1983n, SN1982r is also of type Ib.These four SN constitute all the known examples of type Ib. All of these SNIb exhibit confirmed spectral peculiarity. They apparently belong to the optical subclass of SNI which are characterised by the lack of the normally prominent 6150Å absorption feature. This spectral peculiarity is reported for SN1983n by Panagia (1984), and for 1984l by Wheeler (1984). In fact Wheeler & Levreault (1985) describe the spectra of 83n and 84 l as being virtually identical. Kirshner (private communication, 1985) describes the spectrum of SN1983i as being not that of a regular SNI, but as showing a general resemblance to the spectrum of SN1983n. In particular there is no 6150Å feature. Spectra of SN1982r shows no 6150Å feature, although the evolution of the blue part of the spectrum suggest that the SN was only 20 days from maximum when the data were taken (Muller 1982a). Economy of hypothesis demands that the unusual optical and IR properties of these four SN - the absence of the 6150 Å feature and the lack of IR absorption are in fact characteristics of a *single* subclass of type I supernova.

3) Si in SNIa and SNIb

The 6150Å feature is generally identified as being the blue-shifted absorption wing of a P-Cygni profile due to the 6347Å line of Si II. The absence of this line could be due to a different temperature in the atmosphere of SNIb or to an abundance effect.

The excitation temperature of the lower level of the 6347Å line is ≈ 63000K. The synthetic spectra calculated by Branch for classical SNI indicate that the temperature is ≈20000K and consequently the strength of the line is very sensitive to temperature. The optical-IR colours, and the slope of the continuum of SN1983n indicate that this supernova is unusually red (Panagia 1984, Wheeler & Levreault 1985). Thus at first sight a plausible explanation of the lack of the 6150Å feature would be that SNIb are cooler than SNIa. However, Graham et al. (1985) argue that the extinction towards 83n is high. They find A_V=1.3±0.8, and consequently infer that the colour temperature of SN1983n is not significantly different from a SNIa. It is not obvious at present whether abundance or temperature effects dominate. However, given the lack of clear evidence for a temperature difference between SNIa and SNIb let us assume that the distinction between these sub-classes is due to the abundance of Si.

If the abundance of Si is indeed higher in SNIa than in SNIb then a natural explanation for the IR absorption in SNIa arises if it is supposed that the absorption is caused by Si. Inspection of Grotrian diagrams for Si II does not suggest any candidate line. However, Si I has a dense array of strong IR lines ($A \approx 10^7\ s^{-1}$) arising from the $^3P^o$ and $^1P^o$ terms. The wavelengths of the principal lines are 1.5888, 1.2031, 1.0827 and 1.0585µm. Most of the strong lines fall within the J filter band-passes commonly in use (1.15-1.35µm). Therefore if there is significant optical depth in these lines the continuum at 1.2µm will be depressed.

The excitation temperature of the $^3P^o$ term is ≈ 38000K so the lower states will be well populated at typical temperatures. Thus if there is a significant column density of Si I then the absorption in these lines will be high. The ratio of the optical depths in the 6347Å Si II line and the 1.2031µm

Si I line is given by

$$\tau_{1.2031} / \tau_{0.6347} = 1.2 \, (N_{Si\,I} / N_{Si\,II}) \, (N3p^{o}{}_{2} / N_{Si\,I}) \, (N2S_{1/2} / N_{Si\,II})^{-1}$$

At a temperature of 10^4K $(N3p^{o}{}_{2} / N_{Si\,I}) \, (N2S_{1/2} / N_{Si\,II})^{-1} \approx 50$. Thus if the fractional abundance $N_{Si\,I} / N_{Si\,II}$ is ≈ 0.02 then we expect that the optical depth in the IR lines is comparable to the optical depth at 6347Å. Given the complex structure of the SN atmosphere it is difficult to estimate the ionization state. The ionization potential of Si I is 8.15eV, and consequently one might not expect it to be a very abundant species at temperatures $\approx 10^4$K under conditions of LTE. However, Branch et al. (1983) have identified NaI in the spectra of of SNIa, which has a lower ionization potential (5.14eV). If this ion can be present in abundance then one might also expect to find that Si I can survive.

There should be evidence for Si I in the optical spectra of SNI. Si I has a strong line at 3905Å which should be of comparable strength to the 1.203μm line. At 10^4K $\tau_{0.3905}/\tau_{1.2031} = 0.84$. The optical transition arises from a lower term so this ratio will fall with increasing temperature. Optical spectra of SNIa do indeed show a P-Cygni profile which could be identified with this line. Spectra of SN1981b at maximum show an emission peak at ≈3900Å and associated blue shifted absorption which persists for the period of observation. This feature is attributed to Ca II by Branch et al (1983). Support for this identification comes from the presence of the red Ca II triplet. However, after maximum the ratio of the depths of the blue and the red Ca II features is poorly reproduced by synthetic spectra and the stiuation is further complicated by the blending of the red Ca II lines with an OI line. Clearly the situation is sufficiently complex that it is not unreasonable that a significant fraction of the blue "Ca II" feature could in fact due to SiI. Unfortunately the optical spectra of SNIb which are available (SN1983i, SN1983n and SN1984l) do not extend sufficiently into the blue to beyond 4000Å. It is therefore impossible to ascertain at the moment whether or not this feature is different in SNIa and SNIb.

4) Conclusions

It has been argued that peculiar behaviour in SNI exemplefied by the lack of the 6150 Å Si II feature and the absence of the 1.2μm absorption are characteristics of a single subclass.The idea that Si is responsible for both the 6150Å and 1.2μm absorptions has been investigated and it is shown that Si I posses many strong lines at suitable wavelengths for causing the infrared absorption. The identification of the 1.2μm absorption will not be secure until spectra at this wavelengt become available. However, it will be possible to test this hypothesis by comparing the strength of the 3900Å absorption in SNIa and SNIb. Finally, if the IR absorption is due to Si I then the fundamental difference between SNIa and SNIb is the abundance of Si in the outer layers of the atmosphere.

5) Acknowledgments

I would like to thank Dr Robert Kirshner for providing details of the spectrum of SN1983i in advance of publication. I would also like to acknowledge the encouragement and advice Carl Pennypacker, Saul Perlmutter, Don Morris and Craig Wheeler, and the hospitality of Rich Muller who provided facilities at Berkeley while this work was being carried out. JRG is supported by 1851 and SERC/NATO fellowships.

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